

The same explanation that I ventured to offer in the Bakerian Lecture for 1858, as to the cause of the stratified discharge arising from the impulses of a force acting on highly attenuated but resisting media, is also applicable to the discharge of the voltaic battery in vacua; while the fact of this discharge, even its full intensity having been now ascertained to be also stratified, leads me to the conclusion, that the ordinary discharge of the voltaic battery, under every condition, is not continuous, but intermittent; that it consists of a series of pulsations or vibrations of greater or lesser velocity, according to the resistance in the chemical or metallic elements of the battery, or the conducting media through which the discharge passes.

March 22, 1860.

Sir BENJAMIN C. BRODIE, Bart., President, in the Chair.

In accordance with the notice given at the last meeting, the Right Honourable Edward, Lord Belper, was proposed for immediate ballot; and the ballot having been taken, his Lordship was declared duly elected.

The following communications were read:—

- I. “On the Theory of Compound Colours, and the Relations of the Colours of the Spectrum.” By J. CLERK MAXWELL, Esq., Professor of Natural Philosophy, Marischal College and University, Aberdeen. Communicated by Professor STOKES, Sec. R.S. Received December 27, 1859.

(Abstract.)

Newton (in his ‘Optics,’ Book I. part ii. prop. 6) has indicated a method of exhibiting the relations of colour, and of calculating the effects of any mixture of colours. He conceives the colours of the spectrum arranged in the circumference of a circle, and the circle so painted that every radius exhibits a gradation of colour, from some pure colour of the spectrum at the circumference, to neutral tint at the centre. The resultant of any mixture of colours is then found

by placing at the points corresponding to these colours, weights proportional to their intensities; then the resultant colour will be found at the centre of gravity, and its intensity will be the sum of the intensities of the components.

From the mathematical development of the theory of Newton's diagram, it appears that if the positions of any three colours be assumed on the diagram, and certain intensities of these adopted as units, then the position of every other colour may be laid down from its observed relation to these three. Hence Newton's assumption that the colours of the spectrum are disposed in a certain manner in the circumference of a circle, unless confirmed by experiment, must be regarded as merely a rough conjecture, intended as an illustration of his method, but not asserted as mathematically exact. From the results of the present investigation, it appears that the colours of the spectrum, as laid down according to Newton's method from actual observation, lie, not in the circumference of a circle, but in the periphery of a triangle, showing that all the colours of the spectrum may be *chromatically* represented by three, which form the angles of this triangle.

Wave-length in millionths of Paris inch.

Scarlet.....	2328, about one-third from line C to D.,
Green	1914, about one-quarter from E to F.,
Blue	1717, about half-way from F to G.

The theory of three primary colours has been often proposed as an interpretation of the phenomena of compound colours, but the relation of these colours to the colours of the spectrum does not seem to have been distinctly understood till Dr. Young (Lectures on Natural Philosophy, Kelland's edition, p. 345) enunciated his theory of three primary sensations of colour which are excited in different proportions when different kinds of light enter the organ of vision. According to this theory, the threefold character of colour, as perceived by us, is due, not to a threefold composition of light, but to the constitution of the visual apparatus which renders it capable of being affected in three different ways, the relative amount of each sensation being determined by the nature of the incident light. If we could exhibit three colours corresponding to the three primary sensations, each colour exciting one and one only of these sensations, then since all other colours whatever must excite more than one primary sensa-

tion, they must find their places in Newton's diagram within the triangle of which the three primary colours are the angles.

Hence if Young's theory is true, the complete diagram of all colour, as perceived by the human eye, will have the form of a triangle.

The colours corresponding to the pure rays of the spectrum must all lie within this triangle, and all colours in nature, being mixtures of these, must lie within the line formed by the spectrum. If therefore any colours of the spectrum correspond to the three pure primary sensations, they will be found at the angles of the triangle, and all the other colours will lie within the triangle.

The other colours of the spectrum, though excited by uncompounded light, are compound colours; because the light, though simple, has the power of exciting two or more colour-sensations in different proportions, as, for instance, a blue-green ray, though not compounded of blue rays and green rays, produces a sensation compounded of those of blue and green.

The three colours found by experiment to form the three angles of the triangle formed by the spectrum on Newton's diagram, *may* correspond to the three primary sensations.

A different geometrical representation of the relations of colour may be thus described. Take any point not in the plane of Newton's diagram, draw a line from this point as origin through the point representing a given colour on the plane, and produce them so that the length of the line may be to the part cut off by the plane as the intensity of the given colour is to that of the corresponding point on Newton's diagram. In this way any colour may be represented by a line drawn from the origin whose direction indicates the quality of the colour, and whose length depends upon its intensity. The resultant of two colours is represented by the diagonal of the parallelogram formed on the lines representing the colours (see Prof. Grassmann in *Phil. Mag.* April 1854).

Taking three lines drawn from the origin through the points of the diagram corresponding to the three primaries as the axes of coordinates, we may express any colour as the resultant of definite quantities of each of the three primaries, and the three elements of colour will then be represented by the three dimensions of space.

The experiments, the results of which are now before the Society, were undertaken in order to ascertain the exact relations of the

colours of the spectrum as seen by a normal eye, and to lay down these relations on Newton's diagram. The method consisted in selecting three colours from the spectrum, and mixing these in such proportions as to be identical in colour and brightness with a constant white light. Having assumed three standard colours, and found the quantity of each required to produce the given white, we then find the quantities of two of these combined with a fourth colour which will produce the same white. We thus obtain a relation between the three standards and the fourth colour, which enables us to lay down its position in Newton's diagram with reference to the three standards.

Any three sufficiently different colours may be chosen as standards, and any three points may be assumed as their positions on the diagram. The resulting diagram of relations of colour will differ according to the way in which we begin; but as every colour-diagram is a perspective projection of any other, it is easy to compare diagrams obtained by two different methods.

The instrument employed in these experiments consisted of a dark chamber about 5 feet long, 9 inches broad, and 4 deep, joined to another 2 feet long at an angle of about 100° . If light is admitted at a narrow slit at the end of the shorter chamber, it falls on a lens and is refracted through two prisms in succession, so as to form a pure spectrum at the end of the long chamber. Here there is placed an apparatus consisting of three moveable slits, which can be altered in breadth and position, the position being read off on a graduated scale, and the breadth ascertained by inserting a fine graduated wedge into the slit till it touches both sides.

When white light is admitted at the shorter end, light of three different kinds is refracted to these three slits. When white light is admitted at the three slits, light of these three kinds in combination is seen by an eye placed at the slit in the shorter arm of the instrument. By altering the three slits, the colour of this compound light may be changed at pleasure.

The white light employed was that of a sheet of white paper, placed on a board, and illuminated by the sun's light in the open air; the instrument being in a room, and the light moderated where the observer sits.

Another portion of the same white light goes down a separate compartment of the instrument, and is reflected at a surface of

blackened glass, so as to be seen by the observer in *immediate contact* with the compound light which enters the slits and is refracted by the prisms.

Each experiment consists in altering the breadth of the slits till the two lights seen by the observer agree both in colour and brightness, the eye being allowed time to rest before making any final decision. In this way the relative places of sixteen kinds of light were found by two observers. Both agree in finding the positions of the colours to lie very close to two sides of a triangle, the extreme colours of the spectrum forming doubtful fragments of the third side. They differ, however, in the intensity with which certain colours affect them, especially the greenish blue near the line F, which to one observer is remarkably feeble, both when seen singly, and when part of a mixture; while to the other, though less intense than the colours in the neighbourhood, it is still sufficiently powerful to act its part in combinations. One result of this is, that a combination of this colour with red may be made, which appears red to the first observer and green to the second, though both have normal eyes as far as ordinary colours are concerned; and this blindness of the first has reference only to rays of a definite refrangibility, other rays near them, though similar in colour, not being deficient in intensity. For an account of this peculiarity of the author's eye, see the Report of the British Association for 1856, p. 12.

By the operator attending to the proper illumination of the paper by the sun, and the observer taking care of his eyes, and completing an observation only when they are fresh, very good results can be obtained. The compound colour is then seen in contact with the white reflected light, and is not distinguishable from it, either in hue or brilliancy; and the average difference of the observed breadth of a slit from the mean of the observations does not exceed $\frac{1}{30}$ of the breadth of the slit if the observer is careful. It is found, however, that the errors in the value of the sum of the three slits are greater than they would have been by theory, if the errors of each were independent; and if the sums and differences of the breadth of two slits be taken, the errors of the sums are always found greater than those of the differences. This indicates that the human eye has a more accurate perception of differences of hue than of differences of illumination.

Having ascertained the chromatic relations between sixteen colours selected from the spectrum, the next step is to ascertain the positions of these colours with reference to Fraunhofer's lines. This is done by admitting light into the shorter arm of the instrument through the slit which forms the eyehole in the former experiments. A pure spectrum is then seen at the other end, and the position of the fixed lines read off on the graduated scale. In order to determine the wave-lengths of each kind of light, the incident light was first reflected from a stratum of air too thick to exhibit the colours of Newton's rings. The spectrum then exhibited a series of dark bands, at intervals increasing from the red to the violet. The wave-lengths corresponding to these form a series of submultiples of the retardation; and by counting the bands between two of the fixed lines, whose wave-lengths have been determined by Fraunhofer, the wave-lengths corresponding to all the bands may be calculated; and as there are a great number of bands, the wave-lengths become known at a great many different points.

In this way the wave-lengths of the colours compared may be ascertained, and the results obtained by one observer rendered comparable with those obtained by another, with different apparatus. A portable apparatus, similar to one exhibited to the British Association in 1856, is now being constructed in order to obtain observations made by eyes of different qualities, especially those whose vision is dichromatic.

II. "On the Insulating Properties of Gutta Percha." By FLEEMING JENKIN, Esq. Communicated by Professor WILLIAM THOMSON. Received February 9, 1860.

(Abstract.)

The experiments described in this paper were undertaken with the view of determining the resistance opposed by the gutta-percha coating of submarine cables at various temperatures to the passage of an electric current.

The experiments were made at the works of R. S. Newall and Co., Birkenhead. The relative resistance of the gutta percha at various temperatures was determined by measuring the loss on short lengths